

Efficient Dehydration of Aldoximes to Nitriles Catalyzed by a Lewis Acid Ionic Liquid

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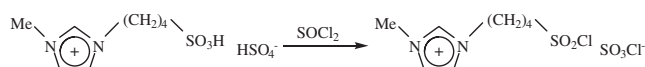
A Lewis acid ionic liquid, 1-[4-(chlorosulfonyl)butyl]-3-methylimidazolium chlorosulfate ([CBMIm]SO₃Cl), with Lewis acid sites in both the anion and cation was synthesized. This was demonstrated to be an efficient catalyst for dehydration of aldoximes to nitriles. An unexpected self-induced phase separation of the reaction mixture was observed when the reaction was carried out in acetonitrile. This could be attributed to the hydrolysis of [CBMIm]SO₃Cl to regenerate 1-(4-sulfo-butyl)-3-methylimidazolium hydrogensulfate ([SBMIm]HSO₄), which was the Brønsted precursor of [CBMIm]SO₃Cl.

Acidic ionic liquids are an important subset of functional ionic liquids that have many important applications in synthetic chemistry.¹ In comparison with conventional catalysts such as AlCl₃, H₂SO₄, HNO₃, or HCl, acidic ionic liquids usually improve catalytic performance, including enhancing the reaction rate, increasing the yield, and simplifying product separation/catalyst recycling.²

Sulfonyl chlorides are usually known as Lobe-LUMO Lewis acids. Recently, we reported the synthesis of some sulfonyl chloride-based Lewis acid ionic liquids and their use as catalysts in synthetic chemistry.³ These Lewis acid ionic liquids had only one Lewis acid site, which was located in either the cation or the anion. As a continuation of this study, we herein report synthesis of a novel sulfonyl chloride-based ionic liquid, 1-[4-(chlorosulfonyl)butyl]-3-methylimidazolium chlorosulfate ([CBMIm]SO₃Cl), which features Lewis acid sites in both the cation and anion. Our primary results showed that [CBMIm]-SO₃Cl was a very efficient catalyst for dehydration of aldoximes to nitriles. Moreover, an unexpected self-induced phase separation was observed when the dehydration reaction was carried out in acetonitrile.

[CBMIm]SO₃Cl was easily synthesized by reaction of the common Brønsted acid ionic liquid 1-(4-sulfo-butyl)-3-methylimidazolium hydrogensulfate ([SBMIm]HSO₄), with SOCl₂ (Scheme 1). To prepare [CBMIm]SO₃Cl, 6 g of SOCl₂ was added dropwise to 10 g of [SBMIm]HSO₄ in a 50 mL flask in an ice water bath. Then the reaction mixture was stirred for 12 h at room temperature. After another 2 h of reaction at 80 °C, excess SOCl₂ was removed from the reaction mixture via vacuum distillation. The remaining yellow liquid was washed with diethyl ether three times, and dried under vacuum at room temperature. The structure of [CBMIm]SO₃Cl was confirmed by high-resolution mass spectrometry (HRMS), ¹H NMR, FT-IR, and element analysis (see Supporting Information; SI⁸).

Dehydration of aldoximes to nitriles is an important reaction in synthetic chemistry. A variety of catalysts, such as diethyl chlorophosphate, palladium, chlorosulfonic acid, and chloral, have been applied to this reaction.⁴ However, only a few examples of ionic liquid-based catalysts have been reported.⁵



Scheme 1. Synthesis of [CBMIm]SO₃Cl from [SBMIm]HSO₄.

Table 1. Catalytic conversion of benzaldehyde oxime in the presence of acidic ionic liquids^a

Run	Solvent	Temp /°C	[SBMIm]HSO ₄		[CBMIm]SO ₃ Cl	
			Conv. /%	Sel. ^b /%	Conv. /%	Sel. ^b /%
1	Toulene	80	7	51	91	81
2	THF	80	10	77	42	95
3	Acetonitrile	80	26	82	79	94
4	Acetonitrile	100	48	90	99	97

^aReaction conditions: ionic liquid, 0.57 mmol; solvent, 3 g; oxime, 2.85 mmol; reaction time, 1 h. ^bSelectivity of benzonitrile.

Therefore, we investigated the catalytic activity of [CBMIm]-SO₃Cl in dehydration of aldoximes. Benzaldehyde oxime was used as the probe substrate in these experiments. For comparison, the catalytic activity of [SBMIm]HSO₄ was also examined, and the results are summarized in Table 1.⁶

Benzaldehyde oxime in an acidic medium commonly reacts via three different pathways, including dehydration to benzonitrile, hydrolysis to benzaldehyde, or the Beckmann rearrangement to benzamide.⁷ Only benzonitrile and benzaldehyde were detected as products when benzaldehyde oxime was treated with the acidic ionic liquids [CBMIm]SO₃Cl and [SBMIm]HSO₄ in different solvents, including toluene, THF, and acetonitrile. Benzamide, the product of the Beckmann rearrangement of benzaldehyde oxime, was not detected in our experiments.

The results showed dehydration of benzaldehyde oxime to benzonitrile depended largely on the catalyst, solvent, and reaction temperature. The Lewis acid [CBMIm]SO₃Cl provided better catalysis of the reaction than the Brønsted acid [SBMIm]HSO₄ in terms of both conversion and selectivity when the reaction was carried out under the same reaction conditions. This enhanced catalytic activity was apparent in all the different solvents tested (Runs 1–4). Increasing the reaction temperature from 80 (Run 3) to 100 °C (Run 4) also enhanced the catalytic activity.

The solvent, especially acetonitrile, played an important role in this reaction. [SBMIm]HSO₄ was immiscible with all of the three solvents, and when it was used as the catalyst the dehydration reaction proceeded in a biphasic manner with a very

Table 2. Dehydration of aldoximes to nitriles in acetonitrile catalyzed by [CBMIm]SO₃Cl^a

Run	Aldoxime	Product	Time/h	Conv./%	Sel./%
1			1.5	93	96
2			1	96	97
3			3	99	98
4			1	97	96
5			1	97	96
6			2	93	99

^aReaction conditions: ionic liquid, 0.57 mmol; acetonitrile, 3 g; aldoxime, 2.85 mmol; reaction temp, 100 °C.

low reaction efficiency. Although [CBMIm]SO₃Cl was also immiscible with toluene and THF, it can show better catalytic performance than [SBMIm]HSO₄, which suggests that the Lewis acid ionic liquid is more favorable for the reaction.

In contrast to [SBMIm]HSO₄, [CBMIm]SO₃Cl was miscible with acetonitrile, and acetonitrile/[CBMIm]SO₃Cl was the most efficient catalytic system for dehydration of benzaldehyde oxime to benzonitrile (Run 4). Interestingly, an unexpected self-induced phase separation was observed when the acetonitrile/[CBMIm]SO₃Cl system was used for dehydration of benzaldehyde oxime to benzonitrile (see SI⁸). The homogeneous solution of acetonitrile/[CBMIm]SO₃Cl/benzaldehyde oxime became biphasic after the reaction finished.

Because [SBMIm]HSO₄ is immiscible with acetonitrile, the biphasic reaction mixture suggested that [CBMIm]SO₃Cl might be converted to [SBMIm]HSO₄ via hydrolysis with water, which is a by-product of the dehydration reaction. To confirm this, the lower phase of the reaction solution was separated and analyzed by HRMS. The results showed that the lower phase was a mixture of [SBMIm]HSO₄ (33%) and [CBMIm]SO₃Cl (67%) (see SI⁸). These results indicate that [CBMIm]SO₃Cl is converted to [SBMIm]HSO₄, and that the acetonitrile/[CBMIm]SO₃Cl system can provide a simple way to separate the product and catalyst.

The acetonitrile/[CBMIm]SO₃Cl system was then applied to dehydration of other aldoximes with high conversion and selectivity (Table 2). The reaction resulted in self-induced phase separation of [CBMIm]SO₃Cl from acetonitrile in all the experiments.

Because [SBMIm]HSO₄ was used as the precursor of [CBMIm]SO₃Cl, the lower phase could be converted into pure [CBMIm]SO₃Cl again by reacting the lower phase with SOCl₂. Our primary results showed that about 96% [CBMIm]SO₃Cl can be recovered (see SI⁸). Then the regenerated [CBMIm]SO₃Cl was reused for dehydration of benzaldehyde oxime to benzonitrile. The catalytic activity for the regenerated [CBMIm]SO₃Cl was almost the same as that for the original catalyst, offering 97% conversion of benzaldehyde and 97% selectivity for benzonitrile. The self-induced phase separation was also

observed. These results suggest that the acetonitrile/[CBMIm]SO₃Cl system can be used as a recyclable catalytic system for dehydration of aldoximes to nitriles with high catalytic performance and simple product separation.

In conclusion, we synthesized a novel ionic liquid, [CBMIm]SO₃Cl, that had Lewis acid sites in both its cation and anion. This ionic liquid was an efficient catalyst for dehydration of aldoximes to nitriles, and had higher catalytic activity than its Brønsted acid precursor. Moreover, the acetonitrile/[CBMIm]SO₃Cl system resulted in self-induced phase separation of the reaction mixture after dehydration of aldoximes to nitriles. We believe this will lead to further applications in acid-catalyzed dehydration reactions, and additional studies are underway.

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References and Notes

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- The typical experimental procedure for dehydration of aldoximes to nitriles in the presence of acidic ionic liquid was as follows: aldoxime (2.85 mmol), solvent (3.0 g), and ionic liquid (20% equiv) were placed in a 10 mL glass test tube. Then the reaction was allowed to proceed at 100 °C for the desired time. After the reaction was finished, the upper phase was analyzed by a gas chromatograph (Shimadzu GC-2014) equipped with a flame ionization detector and an ULBON HR-52 capillary column (25 m × 0.32 mm i.d., Shinwa Chemical Industries Ltd., Japan). Toluene was used as an internal standard.
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- Supporting Information is available electronically on the CSJ-Journal Web site, <http://www.csj.jp/journals/chem-lett/index.html>.